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THE METEOROLOGY OF THE TEMPERATE ZONE AND THE GENERAL ATMOSPHERIC CIRCULATION.¹

551.5 (215-17) : 551.513 Preliminary report by Prof. V. BJERKNES.

[Geofysisk Institut, Bergen, Norway, Apr. 30, 1920.]

SYNOPSIS.

The squall and steering lines of cyclones constitute, when considered together, a line of discontinuity north of which the air is characterized by low temperature, high visibility, dryness, and motion from east and north. South of the line the opposite of these characteristics is the rule. The line of discontinuity, which can be traced for great distances, and, if observations were available, could probably be traced around the entire Northern Hemisphere, has been called the *polar-front line*, and may be regarded as the meeting place of polar and equatorial air.

Loops occasionally form in this line, with the result that masses of warm or cold air are separated from the parent masses. These loops and their results are somewhat dependent upon the latitude of the polar-front line. Such cutting off of air masses represents the formation of HIGHS and LOWS.

The weather of the Northern Hemisphere is the result of the advance and recession of the polar-front line. When the warm air extends farther north than usual, there is a tendency for an accumulation of cold air north of the line. When the pressure from this accumulation becomes sufficiently great, the cold air breaks through and flows southward, causing a change of the type of weather. Thus, the polar-front line is of great importance in forecasting, and, as observations are extended around the earth, it may assist in long-range forecasting.—C. L. M.

In Norway it has been tried from the year 1918 to base the forecasts of the weather on the application of a very close network of meteorological stations. The study of the corresponding *very detailed* synoptic charts has led to interesting results even for the large-scale meteorology. They are due especially to the three young meteorologists J. Bjerknes, H. Solberg, and T. Bergeron, who have been attached to this service, and who will return to the subject in detailed papers.

A very short summary of some of the main results will be given here. They will be seen to give to some extent, both verifications and further developments of ideas, which, although advanced by important theoretical meteorologists, have not yet exerted any noticeable influence upon the development of meteorology.²

The great changes of the weather in our latitudes have been found to depend upon the passage of a line of discontinuity, which marks the frontier between masses of air of different origin.

A line of this kind has first been stated to exist in every cyclone, which is not perfectly stationary. It here borders a tongue of warm air, which from an east-bound current penetrates into a westbound current of cold air (fig. 1). The whole system propagates with the eastbound current, and the cyclonic center with the lowest pressure is in the region where the cyclonic track touches the border of the tongue. The front border, before this point, is curved like a reversed S,

the rear border, behind this point, has a uniform concave curvature. Along the front border warm air from the tongue ascends the barrier formed by the cold air. In return this cold air flows round the tongue in order to penetrate below the warm air along the rear border. Thereby two bands of rain are formed, a broad one in front of the tongue, where the warm air spontaneously climbs the cold, and a narrow one, generally called the squall line, along the rear border, where the advancing cold air violently lifts the warm air of the tongue.³

It has been found by use of the detailed maps, that the line of discontinuity continues even outside the

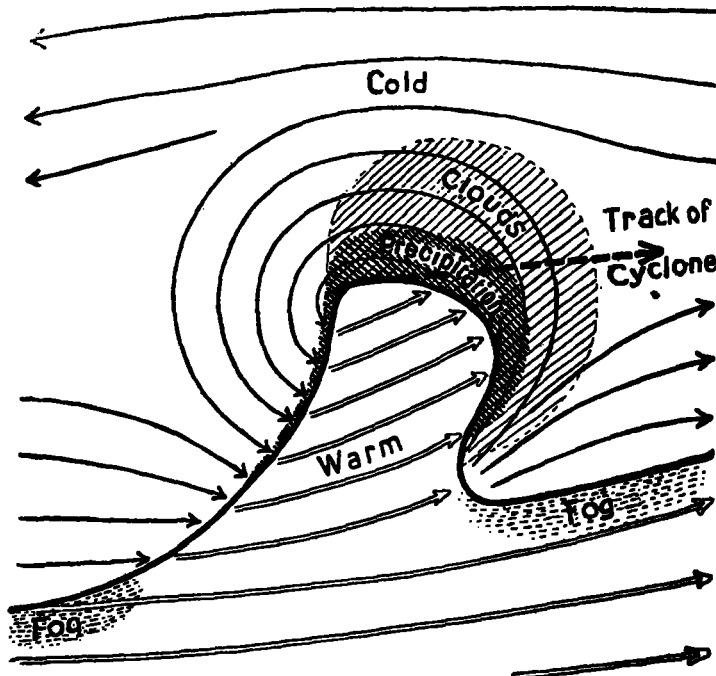


FIG. 1.—Cyclone.

cyclone, passing from the one cyclone to the other: They follow each other along a common line of discontinuity just as pearls on a string.

When one has got acquainted with all the signs, the direct and the indirect ones, which are seen to indicate the position of a line of discontinuity on the very detailed maps, it proves possible to discover them even on less detailed maps. Figure 2 shows roughly the course of such a line, December 31, 1906, as it may be drawn upon the Hoffmeyer maps of the Atlantic Ocean for that day.

¹ Published also in *Nature* (London), June 24, 1920, pp. 522-524.
² *Doug: Das Gesetz der Stürme*, Vierte Auflage, Berlin, 1873. *Helmholtz: Über atmosphärische Bewegungen*, Sitzungsberichte der K. Preuss. Akad. der Wissenschaften 1888, Meteorologische Zeitschrift, 1888. *Brillouin: Vents Contigus et Nuages*, Annales du Bureau Central Meteorologique, 1898. *Margules: Energie der Ströme*, Jahrbuch der K. K. Centralanstalt für Meteorologie, 1903, Anhang.

³ *W. N. Shaw: Forecasting Weather*, p. 212. London, 1911. *J. Bjerknes: On the Structure of Moving Cyclones*, Geofysiske Publikationer, Kristiania, 1919; and *Mo. WEATHER REV.*, Feb., 1919, 47: 95-99.

When similar charts are drawn from day to day, as accurately as circumstances allow, a series of large-scale results very distinctly present themselves.

Though we have been able to draw the line only half round the pole, there can be no doubt that it surrounds the polar regions as a closed circuit. On the northern side of this line all signs indicate air of polar origin; It has a low temperature for the latitude, shows great dryness, distinguishes itself by great visibility, and has a prevailing motion from east and north. On the southern side of the line, the tropical origin of the air is recognized by the corresponding signs; its generally higher temperature, its greater humidity, its haziness, and its prevailing motion from west and south. There can then be no doubt concerning the origin of the line. Heavy cold air flows out along the ground from the polar regions. It is separated from the overlying warmer air by a surface of discontinuity, the height of which above the ground decreases very slowly until it cuts the ground along our line of discontinuity. Thus this line shows

from the scarce observations: these are the places of the great storms and the low barometric pressure. The broad tongues of polar air, on the other hand, bring the clearing up between the successive storms and the corresponding higher barometric pressure.

Two expanding tongues of cold air may occasionally cut off from its base an interjacent tongue of warm air. Then the storm at the polar end is no more supplied by warm air, and it will soon lose its power: this is the death of a cyclone. A tongue of polar air, which has extended itself too much toward the Tropics, may be cut off in a similar way. Or, as the consequence of a new outbreak of polar air, a more retired front may be formed behind a too-far-advanced one. In this way great isolated isles of polar air are formed on lower latitudes; this gives the formation of the great anticyclones, which generally are known to bring steady good weather.

Thus the anticyclones are born in a similar way as the cyclones die. Cyclone and anticyclone and all

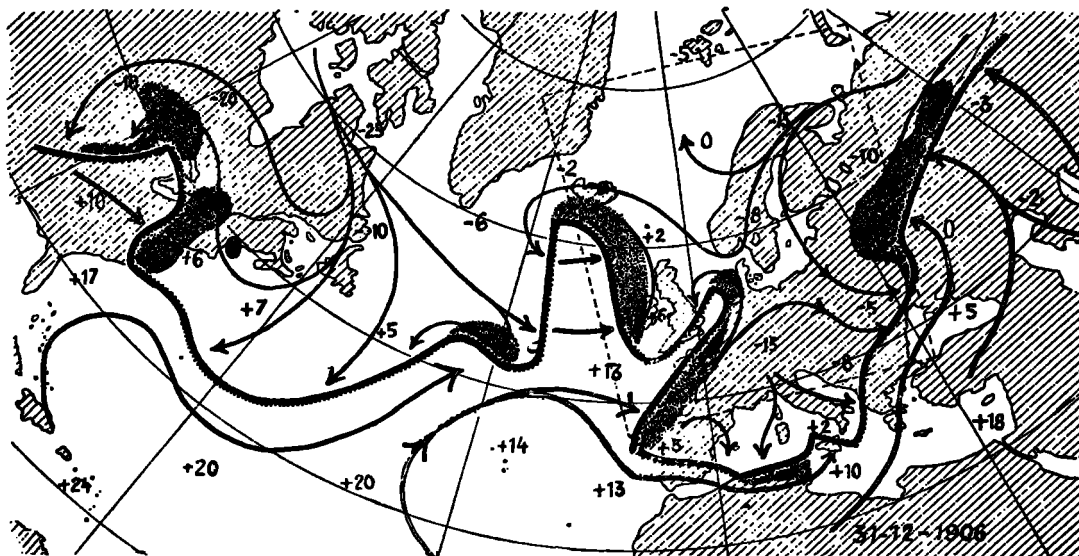


FIG. 2.—Front of polar air Dec. 31, 1906. The rainstorm which is occurring near the Great Lakes arrived at the coast of Norway on Jan. 5, 1907.

how far the cold air has succeeded in penetrating, it is a kind of *polar front-line*.

Along the whole of this front-line, we have the conditions, especially the contrasts, from which atmospheric events originate: the strongest winds, the most violent shifts of wind, and the greatest contrasts in temperature and humidity. Along the whole of the line formation of fog, clouds and precipitation is going on, fog prevailing where the line is stationary, clouds and precipitation where it is moving.

The line has a wavy form, and is in a continuous undulating motion, thereby sweeping over the whole of that zone which is called the temperate. The wavy form comes from alternately cold and warm tongues of air, which extend themselves toward Equator or pole. This whole system is propagating from the west to the east, while the line, at the same time, changes its form, especially when great masses of accumulated cold air are expelled from the central polar regions. The more wavy the form of the line, the more tempestuous and variable is the weather. At the northern ends of the warm tongues, the air motion which characterizes the cyclones is recognized, and the corresponding areas of rain are seen so far as it has been possible to mark them

meteorological events of the Temperate Zone are in the most intimate way related to the polar front and its motion.

This expulsion of great masses of polar air, which leads to the formation of anticyclones, also enters as an essential element into the great atmospheric circulation. There is a practically continuous flow of warm air along the ground from the HIGHS of the subtropic calms toward the polar regions. This flow concentrates itself in the warm tongues and continues into the polar regions in upper levels. Here the air is cooled, and by and by reaches lower levels. Thus increasing masses of cooled air are accumulated behind the polar front. This must continuously advance with the effect that the tracks of the corresponding cyclones are always moved farther toward the south. Finally, at the place of the smallest resistance, great masses of cold air break through and are expelled in the direction of the Tropics. The polar front performs a corresponding retreat, the cyclonic tracks are again displaced to the north, and the type of weather is changed. Then the same play begins over again. This intermittent form of the great atmospheric circulation is especially pronounced in the winter. During the summer, the polar front is far retired, and

the high temperature of the continents exert a considerable influence. Then occasionally a continuous return of polar air may be established along the west coast of the continents and leading direct into the trade winds.

These results can not fail to exert a considerable influence upon the methods of weather forecasting. All meteorological events of the Temperate Zone, great and small, derive from the described great atmospheric circulation, as we know it from the motions of the polar front. If we succeed in watching it effectively, it should be possible to give the short-range forecasts a hitherto unattained accuracy. And it should be possible to complete them by long-range forecasts giving the general character of the weather perhaps for weeks ahead. And these two kinds of forecasts could be extended to all regions of the Temperate Zone, to oceans as well as to continents. The required survey of the polar front is merely a question of organization.

551.524 (048)

PROPAGATION OF COLD AIR ON THE SURFACE OF THE EARTH.¹

By F. M. EXNER.

[Reprinted from *Science Abstracts*, Sect. A, Sept. 30, 1920, §1137.]

The general problem for solution is: Given a mass of dense air of known form and state of motion, covering a small region of the earth's surface, and bounded above and around by less dense air also in known state of motion, to determine the subsequent movement and changes of form of the dense air. The problem is solved for some particular cases in two dimensions, by the hydrodynamical methods applicable to waves at the surface between two fluids of unequal density, but the results sought are mainly qualitative. The dense air is taken initially in the form of a ridge of rectangular cross-section and infinite length. If both fluids are originally at rest, and friction and the earth's rotation are neglected, then the ridge breaks up into two of equal breadth and half the height of the original, traveling in opposite directions perpendicular to their length with a velocity proportional to the square root of the difference of absolute temperature between the cold and warm air. As the ridges move apart the warm air flows in and covers the region of the earth's surface between them. Introducing friction, the ridges separate as before, but decrease in height as they advance, the space between them remaining covered with cold air. In this case, too, the rear of each advancing ridge is higher than the front. On a rotating earth without friction the cold ridge, supposed streaming in the direction of its length, breaks up as before, but the ridge traveling to the left of the direction of streaming (Northern Hemisphere) increases in height, while the other decreases. The velocity of propagation is now greater than before, and the front of each ridge higher than the rear. If the warm air above is streaming at right angles to the ridges, it has the effect of checking the advance of one of them, and may, if strong enough, reverse its motion and make it slowly follow the other, which has its velocity of propagation increased. Other cases are obtained as combinations of these. A comparison is made with observations on the spreading of cold waves over Europe and North America. The author finds in this work an explanation of the phenomena exhibited on these occasions, and in particular of the observed fact that when

cold air breaks through from the polar regions it first seeks to spread W. or SW., then S., SE., E., and often finally NE.—M. A. G.

551.515 (048)

THE ENERGY OF CYCLONES.

In several issues of *Nature* (London) late in 1920 there has appeared a running discussion of the source of the energy of cyclones. There is presented such a concise nontechnical summary of the present ideas of British meteorologists on this intricate subject that extensive quotations are reprinted here. The discussion was started by adverse criticism of Margules's theory by R. M. Deeley. In an obituary of Dr. Max Margules, published in *Nature* (London) October 28, 1920, pp. 286–287,¹ E. Gold gives the following short summary of Dr. Margules's discussion of the energy of storms:

Margules contributed to the Year Book of the Meteorological Institute of Vienna for 1903 a comprehensive discussion of the energy of storms. He showed that the atmospheric phenomena associated with storms would arise if two masses of air of different temperatures were in juxtaposition. The situation would be unstable, and in passing from this unstable situation to a stable one the potential energy would be reduced, part of it being converted into the kinetic energy of the ensuing "storm." This paper contains the germ of the theory of squalls, of the development of cyclones, of polar fronts, and so forth. It concludes computations of the horizontal velocities which would result from various distributions of pressure and temperature, and shows that actual distributions would lead to velocities of 50 miles an hour. Margules summed up his conclusions in the sentence: "So far as I can see, the source of storms is to be sought only in the potential energy of position."

Mr. Deeley, in a letter to *Nature* (Nov. 11 issue, p. 345), criticises many of Margules' points, and concludes with the following sentence:

The facts seem to point to the stratosphere as being the main source of energy of storms and trade winds.

To this Lieut. Col. Gold replies (*ibid.*):

Dr. Margules wrote his paper mainly in connection with phenomena of the line-squall type, but he realized that it might have wider applications, and later investigations do indicate that discontinuity of temperature is the prime factor in the "birth" of cyclones. If one had an atmosphere with uniform pressure at sea level, but with masses of warm and cold air, then at 9 kilometer pressure would necessarily be low in the mass of cold air, and a cyclonic circulation would ensue; but the energy of motion would be derived from the potential energy of the initial state.

Differences of temperature originate in the lower atmosphere. The stratosphere may be able to draw upon a source of energy of which we are ignorant; it can not of itself provide the energy of storms.

In the next issue of *Nature* (Nov. 18, pp. 375–376), W. H. Dines presents the following further discussion:

It does not seem to me as though any really satisfactory theory has yet been put forward to explain the genesis and maintenance of cyclones; I fully agree with Mr. Deeley (Nov. 11, p. 345) that they are not due to contiguous masses of air at different temperatures but, on the other hand, I do not see how they can originate in an inert and stable region like the stratosphere.

Were storms produced by contrasts of temperature—or in other words, by the so-called polar front—surely they would be most violent where the contrast was most marked. The stormiest parts of the world are the great belt of the southern ocean from 40° to 60° S. latitude, and that part of the Atlantic which lies northwest of Scotland, and neither of these regions shows any exceptionally steep gradient of temperature.

Observations in the upper air have shown a remarkable uniformity in the mean temperature (mean with regard to height) from 0 to 20 kilometers in every place where they have been obtained, and it follows as a corollary that there is a very uniform pressure at 20 kilometers height over the globe, for the pressure at 20 kilometers is almost independent of the surface pressure. Observations over Europe, the only part of the world where they are numerous enough for the purpose, have also shown a most extraordinarily close correlation between the temperature and pressure of the air in the upper part of the troposphere,

¹ Akad. Wiss., Vienna, vol. 127, 2a, 1918, pp. 795–847.

¹ Abstract published in *Mo. Weather Rev.*, Oct., 1920, 48:601.